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Support vector regression based models to predict fracture characteristics of high strength and ultra high strength concrete beams

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ABSTRACT

This paper examines the applicability of support vector machine (SVM) based regression to predict fracture characteristics and failure load (P_{max}) of high strength and ultra high strength concrete beams. Characterization of mix and testing of beams of high strength and ultra strength concrete have been described briefly. Methodologies for evaluation of fracture energy, critical stress intensity factor and critical crack tip opening displacement have been outlined. Support Vector Regression (SVR) is the extension of SVMs to solve regression and prediction problems. The main characteristics of SVR includes minimizing the observed training error, attempts to minimize the generalized error bound so as to achieve generalized performance. Four Support Vector Regression (SVR) models have been developed using MATLAB software for training and prediction of fracture characteristics. It is observed that the predicted values from the SVR models are in good agreement with those of the experimental values.

1. Introduction

Concrete has been one of the most commonly used construction materials in the world. One of the major problems civil engineers face today is concerned with preservation, maintenance and retrofitting of structures. The historical development of concrete material may be marked and divided into several stages. The first is the traditional normal strength concrete followed by high strength concrete, high performance concrete and reactive powder concrete/UHSC. Since UHSC is a relatively new material, the fracture behavior of this material is not well understood [1–4]. UHSC is successfully applied in the field for the construction of Sherbrook Pedestrian Bridge, Canada, The Glenmore/Legs by Pedestrian, Alberta, Canada and Π shaped UHPC beams installed in footbridges in Auckland, New Zealand [5,6]. Concrete is a quasi-brittle material, which means its fracture process zone (FPZ) size is not small compared with the typical specimen or structural dimension. Classical linear elastic fracture mechanics (LEFM) approach is unable to predict the progressive failure of concrete specimens due to the presence of large FPZ of variable size ahead of the crack tip and the cohesive stress transferred within FPZ of the quasi-brittle materials like concrete [7]. The LEFM based modeling approach assumes that once a crack propagates by a distance, this part of the material loses its load carrying capacity suddenly and completely. The complex nonlinear phenomena that take place in FPZ can be idealized and approximated using nonlinear fracture approaches to predict the localized physical behavior in

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Nomenclature

P_{max}	failure load (kN)
G_F	fracture energy
K_{IC}	critical stress intensity factor
$CTOD_c$	critical crack tip opening displacement
w	crack mouth opening displacement
W_F	work of fracture
P	applied load
d	depth of the beam
a_0	initial crack length
t	thickness of the beam
C_i	loading compliance
C_u	unloading compliances peak load (P_c)
P_0	self-weight of the specimen
a_c	critical effective elastic crack length at the peak load
E_1	modulus of elasticity obtained with the loading compliance
E_2	modulus of elasticity obtained with the unloading compliance
g_2	geometric factor for evaluation of modulus of elasticity
g_1	geometric factor for evaluation of stress intensity factor
S/D	span to depth ratio
S	span
D	depth of the specimen
L	length of the specimen
ε	error
L_ε	error insensitive loss function
y_i	target output
ξ_i^*, ξ_i	slack variables
C	positive constant parameter
α_i^*, α_i	Lagrange multipliers
$x_i \cdot x_j$	inner product of two training patterns x_i and x_j
b	bias
X_i	input training pattern
$\varphi(x)$	mapping function from the input feature to a higher dimensional feature space
$\varphi(x_i)\cdot\varphi(x_j)$	inner product
x_i	training pattern
x	test pattern
d	a dimension of the input vector
σ	global basis function width or the width of the kernel function
x_i^a	ith component of the input vector without normalization
x_i^n	normalized value of ith component of the input vector
x_i^{max}	maximum value of all the components of the input vector (in corresponding columns) value without normalization
x_i^{min}	minimum value of all the components of the input vector without normalization (in corresponding columns)
R	coefficient of correlation
R^2	coefficient of determination
A	c/s area of the specimen
w/c	water–cement ratio
f_{ck}	compressive strength
σ_t	split tensile strength
E	modulus of elasticity

the vicinity of a crack and at the crack tip. Nonlinear fracture mechanics based approach recognizes that FPZ exists in front of the crack tip, in which the material can still carry loadings by mechanisms such as aggregate interlocking, surface friction and material bonding. As the crack propagates and opens, the material in FPZ softens with gradual energy dissipation, which can be accurately modeled by the fictitious crack model. The crack propagation direction is assumed to be perpendicular to the direction of the maximum stress at the cohesive crack tip. The cohesive crack model is one of such simplified nonlinear fracture models that can simulate satisfactorily the behavior of concrete fracture. Inspired by the early stage of development of the fracture models [7–9]. Hillerborg et al. [10] initially applied cohesive crack method (or fictitious crack model) as a suitable nonlinear model for mode I fracture to simulate the softening damage of concrete structures.